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ON THE QUESTION OF EFFICIENT EXTRACTION OF ELECTRONS FROM A PLASMA IN A VACUUM

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ON THE QUESTION OF EFFICIENT EXTRACTION OF ELECTRONS FROM A PLASMA IN A VACUUM

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ABSTRACT. It is found that the Penning discharge with cold cathodes as an auxiliary discharge in a plasmatron extends the capabilities of this type of devices. The deformation of the transverse magnetic field helps to reduce the operating pressure and increase the electron current.

Two electron current extraction regimes in a vacuum, from a plasma, formed /151* in a system of electrodes enclosing a Penning tube were examined in [1]. Conditions were found under which this system provides in a vacuum electron currents up to 20 A, constituting a significant part of the discharge current. The flow of such currents with a density of more than 100 A/cm^2 over a distance of the order of 1 mm for a voltage of about 100 V is possible only with compensation for the negative space charge by the positive ions as a result of transfer of the discharge burning in the Penning tube to the extracting electrode. Some essential aspects of the processes which determine the observed effective extraction of ampere-level currents remain unclear. In particular, it would be helpful to clarify whether or not effective current extraction is associated with the characteristics of the Penning discharge or whether similar phenomena can be observed when using auxiliary discharges of other types and also when replacing the auxiliary electrode by a thermocathode.

In our experiments, we used the electrode system described in [1], but the Penning discharge can be replaced by the discharge between the directly heated tungsten thermocathode 1, introduced into the central region of the rectangular anode 2 of the Penning tube, and this anode, which is electrically connected

* Numbers in the margin indicate pagination in the original foreign text.

with the cold cathodes 3 of the tube (Fig. 1). The working gas, argon, was admitted into the discharge chamber, connected with the extracting gap and the rest of the high-vacuum space by a 2-mm-diameter emission port. When replacing the auxiliary discharge by the thermocathode, the latter was mounted in the plane of the emission port and was connected electrically with the anode (switch K in position 1). The extracting ferromagnetic electrode 4, which deforms the magnetic field in the region of the emission port [2], was located 1 mm from the anode. The Faraday cup 5 was located some distance from the extracting electrode to ensure a low pressure in the space between them. Transition to the effective current extraction regime was determined by the sharp increase of the overall current I_0 on these electrodes. The pressure P_p in the Penning tube and the pressure P_k in the high-vacuum space were measured during the experiment.

In [1], discharge and output currents up to 20 A were provided in the pulsed regime when using a Penning discharge with cold cathodes. In the case of discharge with a thermocathode, operation with such currents is difficult, since the thermocathode requires power continuously, regardless of the current extraction conditions, and the emission surface area and heater power required are too large for the use of the experimental system. Therefore, the experiments described below were conducted in the continuous regime with relatively /152 low currents. However, preliminary investigations of the Penning discharge showed that the effective current extraction regime, which in principle makes it possible to obtain high currents in a vacuum, under certain conditions also manifests its characteristic features at small currents.

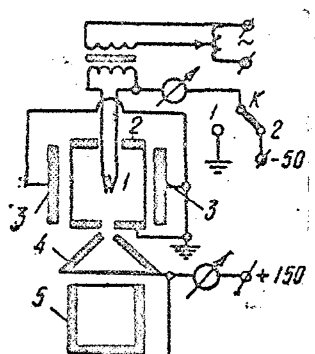

Figure 1. Experiment schematic

Figure 2 shows the curves of the cathode current I_k, and the output current I_0, for these cases: an auxilary Penning discharge with cold cathodes, burning at a voltage of 500 V in a 500-Oe magnetic field (Fig. 2a), an auxiliary discharge burning between a thermocathode and the Penning tube with a voltage of 50 V (Fig. 2b), and a thermocathode located in the emission port (Fig. 2c). In all the experiments, the voltage in the gap between the tube anode and the extracting electrode was 150 V. In order to make it possible to evaluate the pressure in the gap, the pressure values in the high-vacuum space are also plotted along the horizontal axis.

In both cases using auxiliary discharges, the output current I_0 initially rises slowly with increase of the pressure as a result of ionization in the electric field of the extracting electrode. Then, when the critical pressure P_{cr} is reached, having the same value for both discharges within experimental error, the output current increases abruptly to a value which exceeds the cathode current, as a result of initiation of a discharge to the extracting electrode, and remains practically constant with further increase of the pressure.

In the case of the thermocathode located in the emission port, initiation of the discharge to the extracting electrode occurs under approximately the same conditions as in the presence of the auxiliary discharges (Fig. 2c).

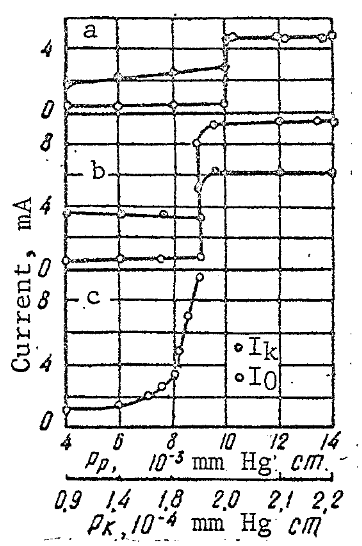

Figure 2. Electrode currents versus pressure.

Figure 3 shows the critical pressure P_{cr} versus the cathode current of an auxiliary discharge with a thermocathode, which is controllable by variation of the heating current. The shape of the curve indicates that for high discharge currents, the critical pressure does not depend on the discharge current of the auxiliary discharge.

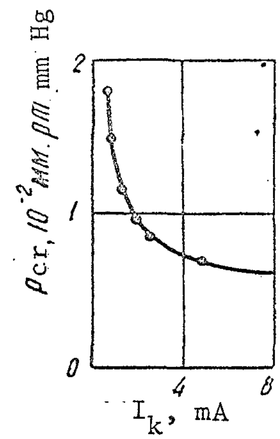

Figure 3. Critical pressure versus cathode current.

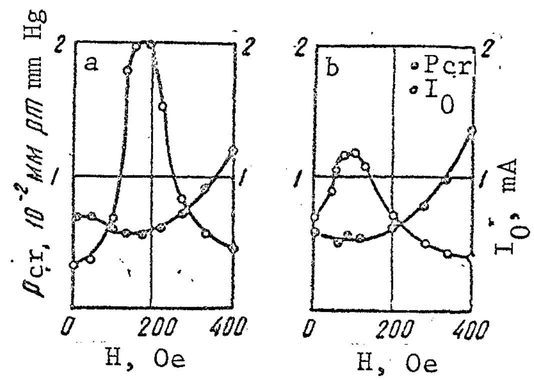

Figure 4. Critical pressure and output current versus magnetic field intensity.

In order to clarify the role of the magnetic field in the transition to the effective current extraction regime, we obtained the curve of the critical pressure as a function of the magnetic field intensity in the Penning tube (Fig. 4), for the case of a discharge with a thermocathode. Also, shown in this figure is the curve of the output current I_0, preceding transition. The extrema of the curves coincide. The increase of the current through the emission port in the anode and the corresponding decrease of the critical pressure are in agreement with the concept of the role of magnetic field deformation by the ferromagnetic extracting electrode [2]. The reduction of the output current for high magnetic fields is obviously a consequence of drift of electrons, from the thermocathode, along the magnetic field, to the cold cathodes of the Penning tube, which are connected electrically with the tube anode. However, the left branches of the curves (Fig. 4a) cannot be explained by magnetic field deformation alone, since experiments with a diamagnetic extracting electrode yield the same nature of the relationship, although less marked (Fig. 4b). The magnetic field corresponding to the left branches of the curves of Fig. 4 cannot have any significant effect on the ionization processes in the extracting gap, at least prior to initiation of the low-voltage discharge to the extracting electrode, since extimates show that the electron cycloidal trajectory arc height is greater than the gap length. We must then assume that the magnetic field affects the initiation of the low-voltage discharge, amplifying the ionization of the gas in the electric field of the extracting electrode, which penetrates into the Penning tube through the anode aperture. The possibility of intense ionization in this region is associated with the high pressure, in comparison with the extracting gap, and the elongation of the electron trajectory in the crossed fields. An indirect confirmation of this possibility is the experimentally observed increase of the optimal magnetic field with increase of the extracting voltage. /152

These experiments form a basis for concluding that the regime examined in [1], of effective electron extraction from a plasma, in a vacuum is not associated with the characteristics of the Penning or any other auxiliary discharge, and is always observed when a sufficient number of electrons are introduced through a small aperture into a gap of certain definite geometry at some pressure. When using a thermocathode located in the central part of the Penning tube, the electrode system considered here (Fig. 1), is essentially similar to the discharge chamber of the plasmatron [3], which is used, in particular, to obtain ionic and electronic beams. It is known that the discharge from the thermocathode in such a device may be replaced by an arc discharge from a hollow cold cathode [4]. The use of the Penning discharge with cold cathodes as an auxiliary discharge in a plasmatron extends the capabilities of devices of this type. The deformation of the transverse magnetic field, which is necessary to maintain the Penning discharge, in the region of the emission aperture helps to reduce the operating pressure and increase the electron current.

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